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A SIMULATION STUDY OF AN OPTIMIZATION MODEL FOR SURFACE NUCLEAR ACCESSION PLANNING

by

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A Simulation Study of an Optimization Model for Surface Nuclear Accession Planning

by

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ABSTRACT

This thesis examines a nontraditional approach to a manpower planning problem. This approach combines two operations research methodologies: simulation and optimization. The combined approach, which is referred to as SIMOP, models the manpower planning problem as a linear program and, through simulation techniques, allows the input data to be random. Based on the experimentation performed in this study, the average results from the SIMOP model can be quite different from the result obtained using a traditional optimization model. Also presented are applications of the SIMOP model to military manpower planning.

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I. INTRODUCTION

With the tightening of budgetary constraints during this decade, the Navy has accepted the challenge of meeting its obligations with limited assets. Throughout the Navy, programs have been reassessed and streamlined, cut or otherwise made more economical. While manpower programs are not exempt from cost reduction efforts, it is essential in meeting the missions of the U.S. Navy that its fleet be manned with the proper number and quality of officer and enlisted personnel. Thus the objective of minimizing manpower costs must not be attained at the expense of adequate manning. Rather, cost reductions must be achieved by bringing the correct mix of personnel into the service.

While many manpower modeling techniques can be applied to the problem faced by the Navy, this thesis examines a rather nontraditional approach. Traditionally, problems of this type have been solved by using optimization techniques and employing a Markov chain model. This methodology is addressed by Grinold and Marshall [Ref. 1] and is exemplified by The Army Manpower Long-Range Planning System [Ref. 2].

Markov chain manpower models typically employ transition matrices whose elements are assumed to be known and deterministic. When a Markov chain model is employed within an optimization program, the program typically minimizes an objective function, e.g. total cost, while satisfying constraints such as filling all job positions with the necessary personnel.

A. A PROPOSED METHODOLOGY

The core of the model presented in this study consists of a linear programming model formulated to minimize total cost subject to two classes of constraints. One allows officers to be retained & promoted, retained & not promoted, and leave the service, and the other guarantees that all billet requirements are fulfilled. Unlike the traditional models in manpower planning, the data required by this model are allowed to vary stochastically as random variables.

With random data, a stochastic programming model is often developed. However, in stochastic programming, one is generally interested in a single solution which optimizes the objective function and satisfies the constraints for all possible values of the random variables. One such solution does not reflect the true, uncertain nature of the results, and, moreover, a stochastic programming model of the size and form considered in this thesis would be quite difficult to solve. Instead, this study focuses on the behavior of the optimal solution to the linear programming model as a function of the random data. It is believed that an analysis of such behavior provides more useful information to planners. To this end, a simulation approach combined with an optimization (SIMOP) model is adopted.

In the SIMOP model, one replication of the simulation consists of generating a set of (pseudo) random data for the linear programing model and solving the resulting problem by the simplex method (see Figure 1). By performing a sufficient number of replications, the solutions to the linear programming model can be analyzed statistically. The resulting analysis would augment and complement the information already available to, e.g. nuclear officer personnel planners.

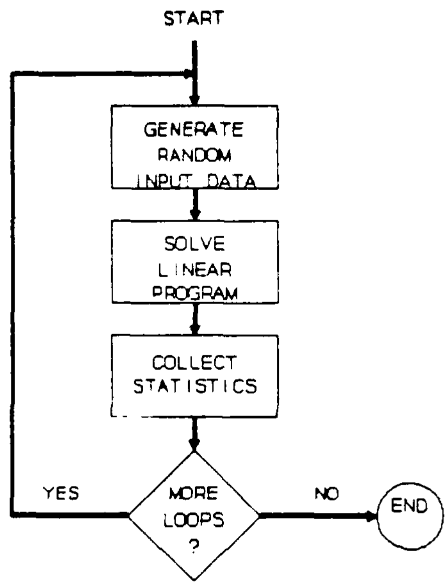

Figure 1: Flowchart of SIMOP Process

While the SIMOP model cannot replace current decision making processes, its value and potential should not be overlooked. For example, the optimal mix provided by the model could be used by planners as a basis against which to compare other possible mixes, or, by varying input parameters, the consequences of implementing proposed policies could be studied. Thus, the model provides more than just an optimal mix which may or may not be desireable based on criteria other than minimum cost. It also provides a feasible solution which can profitably be used in comparative analyses and a means by which to explore alternatives.

B. PROBLEM DESCRIPTION AND THESIS OUTLINE

Each year the Navy's nuclear personnel planners must set target values for the number of entrants from the United States Naval Academy (USNA), the Naval Reserve Officers Training Corps (NROTC), and the Nuclear Propulsion Officer Candidate (NUPOC) program. Ideally, the target values are set such that

1) all billet requirements will continue to be met and

2) the total personnel cost to the Navy, including precommissioning costs and salary, is minimized.

The difficulty in achieving these goals is caused by uncertainty surrounding future retention and promotion rates. The following chapters present one approach to dealing with that uncertainty.

The linear programming model and its implementation in the General Algebraic Modeling System (GAMS) are described in the Chapter II. Chapter III details the input data for the linear programming model and the methods used to generate it. Appendix B supplements Chapter III where required. The fourth chapter compares the results from the SIMOP model and the traditional optimization model and presents a set of applications for the SIMOP model. Conclusions and recommendations are presented in Chapter V.

II. MODEL DESCRIPTION

The linear programming (LP) model described in this chapter minimizes the cost of the entrants into the nuclear surface warfare officer community for each of the next five fiscal years. The constraints in the model include a) (supply) equations which limit the number of officers commissioned from each source in a fiscal year, b) (demand) equations which represent the billet requirements for each year, and c) (flow balance) equations which allow for the advancement in rank and years of service of the officers. The next two sections formulate the problem mathematically.

A. MODEL FORMULATION

The formulation of the linear programming model is presented here in a compact format to introduce the model without providing a cumbersome level of detail. The formulation is in a format commonly used at the Naval Postgraduate School.

Indices

I	Accession Source	(USNA, NROTC, NUPOC)
J	Years of Service	(0,1,2,...,24)
K	Rank	(O1,O2,...,O6)
L	Calendar Year	(1988 - 2017)

Data

POSS(J,K,L) =	{ 1 if an officer with J years of service can be rank K in year L; 0 otherwise
BR(K,L)	- Number of billets that will require an officer of rank K in year L
CA(I,L)	- Cost of an accession from source I in year L
CF(I,J,K)	- Cost of an officer from source I with J years of service and rank K
SFC	- Cost of shortfall
M(I,L)	- Upper bound on the number of accessions from source I in year L
RNP(I,J,K,L)	- Random proportion of officers from source I with J years of service and of rank K that will be retained but not promoted in year L
RAP(I,J,K,L)	- Random proportion of officers from source I with J years of service and of rank K that will be retained and promoted in year L
X(I,J,K,1988)	- Number of officers from source I with rank K and J years of service at the start of the planning period, i.e., 1988

Variables

X(I,J,K,L)	- Number of officers from source I with J years of service and rank K in year L
SF(K,L)	- Number of billets in rank K in year L that are not filled

Formulation

minimize: $\sum_{I}\sum_{L} CA(I,L) \cdot X(I,0,01,L) + \sum_{K}\sum_{L} SFC \cdot SF(K,L)$

$+ \sum_{I}\sum_{J}\sum_{K}\sum_{L} CF(I,J,K) \cdot X(I,J,K,L)$

subject to:

1) $\sum_{I}\sum_{J} X(I,J,K,L) + SF(K,L) \geq BR(K,L)$ for all ranks K and years L

2) $X(I,0,01,L) \leq M(I,L)$ for all sources I and years L

3) $X(I,J+1,K,L+1) = RNP(I,J,K,L) \cdot X(I,J,K,L)$ for all sources I, years of service J, years L and for rank K = 01

4) $X(I,J+1,K+1,L+1) = RAP(I,J,K,L) \cdot X(I,J,K,L) + RNP(I,J,K+1,L) \cdot X(I,J,K+1,L)$ for all sources I, years of service J, years L and for rank K > 01

B. DETAILED DESCRIPTION

1. The Objective Function

The cost function which is minimized by the model includes costs which vary depending on the commissioning source of an officer. Both precommissioning and postcommissioning costs are considered; however, as this is not an attempt to do a detailed cost analysis, costs which are not source dependant (i.e. bonuses, retirement pay, and pay other than base pay) are not incorporated into the model. Thus, postcommissioning costs include only base pay, which must be considered since officers commissioned from Officer Candidate School (OCS) via the NUPOC program receive credit for pay purposes only for the years of service prior to commissioning. Precommissioning costs vary widely between sources and, therefore, must also be considered.

Shortfall variables, SF(K,L), are included in the model to ensure problem feasibility. By assigning a high cost to these variables, they will be positive only when the original problem is truly infeasible, i.e., when there are not enough officers to fill all billets.

2. The Constraints

Demand constraints, equation (1), ensure that there is a sufficient number of officers to fill all billets requiring a nuclear trained surface warfare officer. As seen in the Section A and discussed above, shortfall contributes to the "filling" of billet requirements. In the fleet, there are insufficient numbers of O4's to fill all O4 billet requirements, and senior O3's are used to fill O4 billets. This practice is called "up-detailing" and is frequently used. Equation (1) as stated in Section A allows no up-detailing. However, in Chapter IV, several up-detailing policies are considered, and equation (1) is modified to reflect the change in policy.

Supply constraints, equation (2), force the solver to include no more than the anticipated number of available candidates in the optimal mix. Since shortfall is included in the demand constraints, no "dummy" variables are required in the supply constraints to ensure feasibility.

Equality constraints, equations (3) and (4), are used to advance a group of entrants through ranks and years of service. Figure 2 depicts the relationships between decision variables, X(I,J,K,L), in a network form. The number of officers in a class I,J,K (a "class" is a specific combination of rank, years of service, and commissioning source) during year L+1 is determined by the number of transitions into the class at the end of year L. Transitions into class I,J,K can originate from only two classes: class I,J-1,K-1 and class I,J-1,K, since an officer's commissioning source (I) is constant, his years of service (J) always increment by one, and his rank (K) either stays the same or is incremented by one grade. Therefore, the number of officers in class I,J,K in year L+1 depends on the number of officers in each originating class in year L and on the probability of transition from the originating class to class I,J,K. Equality constraints (3) and (4) represent the transition of

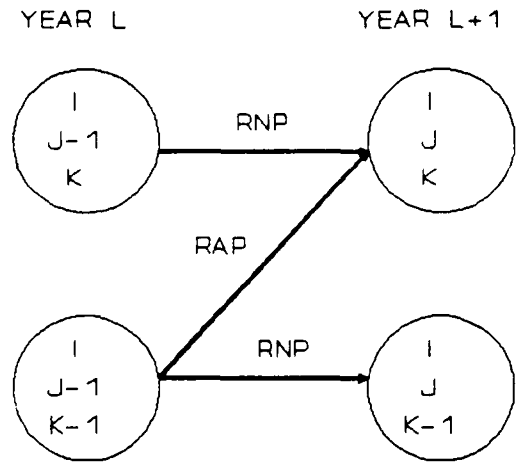

Figure 2: Example of Relationships Between Decision Variables

officers from zero years of service to twenty-four years of service (or until they are no longer retained in the nuclear surface community) and up to the rank of O6.

C. GAMS IMPLEMENTATION

The General Algebraic Modeling System (GAMS) developed under the direction of Meeraus was selected for the simulation of the LP model presented above. GAMS possesses two convenient features essential to this study: looping [Ref. 3:pp. 138-139] and random number generation [Ref. 3:p. 69]. Looping allows a large number of replications to be performed with a minimum number of program statements. GAMS has two internal functions (subroutines) to generate uniform and normal random numbers necessary to generate the stochastic input data for the model. The listing of the GAMS program is provided in Appendix A and the significant aspects of GAMS implementation are discussed below.

1. Variable and Equation Reduction

The LP problem in the form stated above contains many variables and equations which do not affect the solution to the model. In an effort to eliminate these inessential parts and thus improve program efficiency, the dollar operator in GAMS is utilized.

The variable X is indexed by I, J, K, and L. If all possible classes (I,J,K,L) are allowed there would be 13,500

(3 sources · 25 years of service · 6 ranks · 30 years) X-variables in the model. Initial variable reduction is accomplished by considering only the combinations of years of service (J) and rank (K) which have historically occurred with regularity. After eliminating X(I,J,K,L) variables with uncommon or unrealistic combinations of J and K, only 2,790 X-variables remain.

Since only those remaining variables which will interact with the groups of entrants in years 1989 through 1993 are required, many combinations of years of service, rank, and year are also eliminated. For example, a commander with twenty years of service in 1990 will never compete for a billet against an officer commissioned in 1989 through 1993. Thus, this commander is not considered in the model, and variable X(I,'20','O5','1990') is eliminated.

Variable reduction is accomplished in GAMS through the use of the dollar operator and the table POSS(J,K,L), which contains a "1" for all combinations of years of service, rank, and year which are considered in the model (with the exception of groups of officers who have not completed their first year of service). Following the variable reduction, only 1,479 X-variables of the original 13,500 remain.

Similarly, the number of constraint equations generated by GAMS is reduced by using the dollar operator. As an example, equation SUPPLY is generated only for years 1988 through 2000 since no officers commissioned after year 2000 will interact with those officers in the groups of interest (entrants during years 1989 through 1993). Following the equation reduction, only 1,512 equations of the original 13,231 remain.

2. Random Number Generation

The proportion of officers in a class who are retained & promoted from year to year are shown in Chapter III to be independent random variables and are modeled as the proportion parameter, p, of a binomial distribution. When the number of observations permits approximation by normal random variables, the GAMS function NORMAL is used to generate the random proportions prior to solving the LP model. Otherwise, GAMS' uniform random number generator, the function UNIFORM, is used in a routine to generate binomial random numbers. Such a routine may be found in standard textbooks on simulation [Ref. 4] and is described in Section B of the next chapter.

III. INPUT DATA

Input data for the model include cost data, billet requirements, retention and promotion fractions, upper bounds on the number of entrants available from a commissioning source, and initial manning levels. The analyses of the raw data used to derive the model input and the assumptions made in performing the analyses are described in the following sections. Where required, detail is provided in Appendix B.

A. BILLET REQUIREMENTS

The approximate number of billets, by rank, to be filled by nuclear trained surface warfare officers in 1989 was provided by the Naval Military Personnel Command (NMPC-412N) from the Billet Master File. Billet requirements for each rank are assumed to remain constant over time. This assumption is rational since the billet requirements for 1989 include billets for the two newest Nimitz class nuclear aircraft carriers, and no decommissioning of nuclear powered ships can be anticipated before 2017, the last year considered in the model. The table of billet requirements (by rank and by year) is contained in the GAMS listing in Appendix A.

B. RETENTION AND PROMOTION FRACTIONS

The process of retention and promotion of officers was modelled as a binomial random process with proportion p being associated with the probability of an officer being retained & promoted. One point estimator of p is given by

$$\hat{p} = X/n,$$

where X represents the number of officers retained & promoted out of n total officers. For values of p such that np and n(1-p) are both greater than or equal to five, $\hat{p}$ is approximately normally distributed with mean

$$E[\hat{p}] = E[X/n] = \frac{np}{n} = p$$

and variance

$$VAR[\hat{p}] = VAR[X/n] = \frac{VAR[X]}{n^2} = \frac{npq}{n^2} = \frac{pq}{n},$$

and random values for $\hat{p}$ can be generated using a normal random number generator. When the normal approximation is not appropriate, random values for $\hat{p}$ can be generated by simulating a sequence of Bernoulli trials and dividing the number of successes by the number of trials.

Note, however, that the variance of $\hat{p}$ depends on n. In the linear programming model, n corresponds to the number of officers eligible for promotion for each combination of rank, years of service, and year. At the start of each replication of the simulation, the value of n is unknown, and an estimate of n is used in the above formula for $VAR[\hat{p}]$.

The following paragraphs describe the estimation of $\hat{p}$ and its variance for all combinations of rank, years of service, and year.

1. Developing the Point Estimator

The Defense Manpower Data Center (DMDC) in Monterey, California, provided the raw data from which retention and promotion figures were derived. For years 1978 through 1988, the social security number, rank, years of service, and commissioning source were extracted from their main files for all commissioned naval officers with a surface warfare designation and an Additional Qualification Designator signifying completion of nuclear training.

A Fortran program was written to convert the extracted information into retained & promoted and retained & not promoted proportions. The program examines data from two successive years and calculates the fraction of officers from each class (i.e. with each combination of commissioning source, years of service and rank) that were retained & promoted and the fraction retained & not promoted. For example, the fractions were calculated for Lieutenants from the NUPOC program with four years of service for years 1978 through 1987. These fractions were saved in output files which were subsequently imported into STATGRAF, a statistics and graphics package for the personal computer. Since retained & promoted fractions and retained & not promoted fractions were analyzed in the same manner, only the analysis of retained & promoted data is described in the following paragraphs.

STATGRAF was used to analyze the retention and promotion fractions and to verify assumptions about the distributions of the fractions. Initially, the data were graphed on scatter plots with the ten data points (retained & promoted fractions) for each class plotted against the year with which the point is associated. The scatter plots (a typical case is depicted in Figure 3) reveal little other than that the fractions do not show a definite trend over time. This lack of dependance was verified by performing linear regressions (see Figure 4) on the data with "year" as the independent variable. Generally poor fits were obtained, and hypothesis testing based on the "Analysis of Variance for the Full Regression" table (see Table 1) produced by STATGRAF led to a failure in almost all cases to support an assumption of a time dependance.

The independence of successive years' data was further explored by examining the autocorrelation coefficients for the series of values. Again, the analysis supported the assumption that the observed fractions were, for a given class, independent observations.

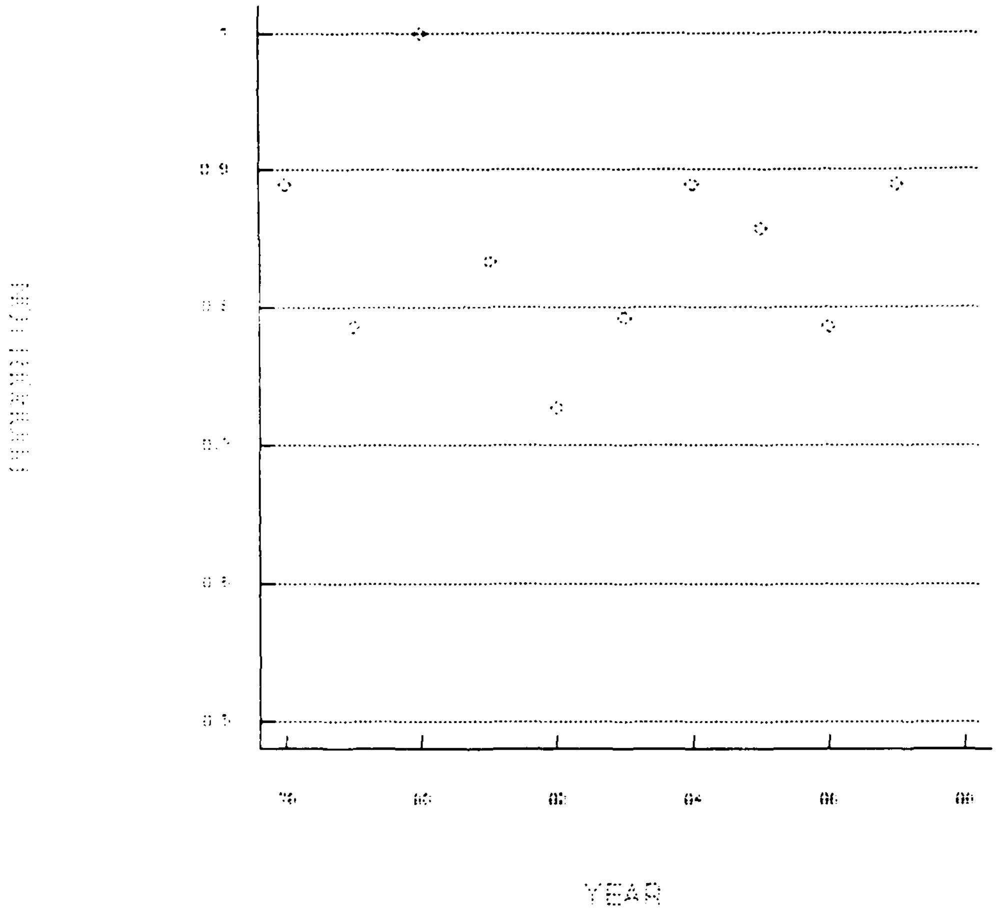

Figure 3: Proportion of O3's with 6 Years of Service from USNA that are Retained and Not Promoted, by Year

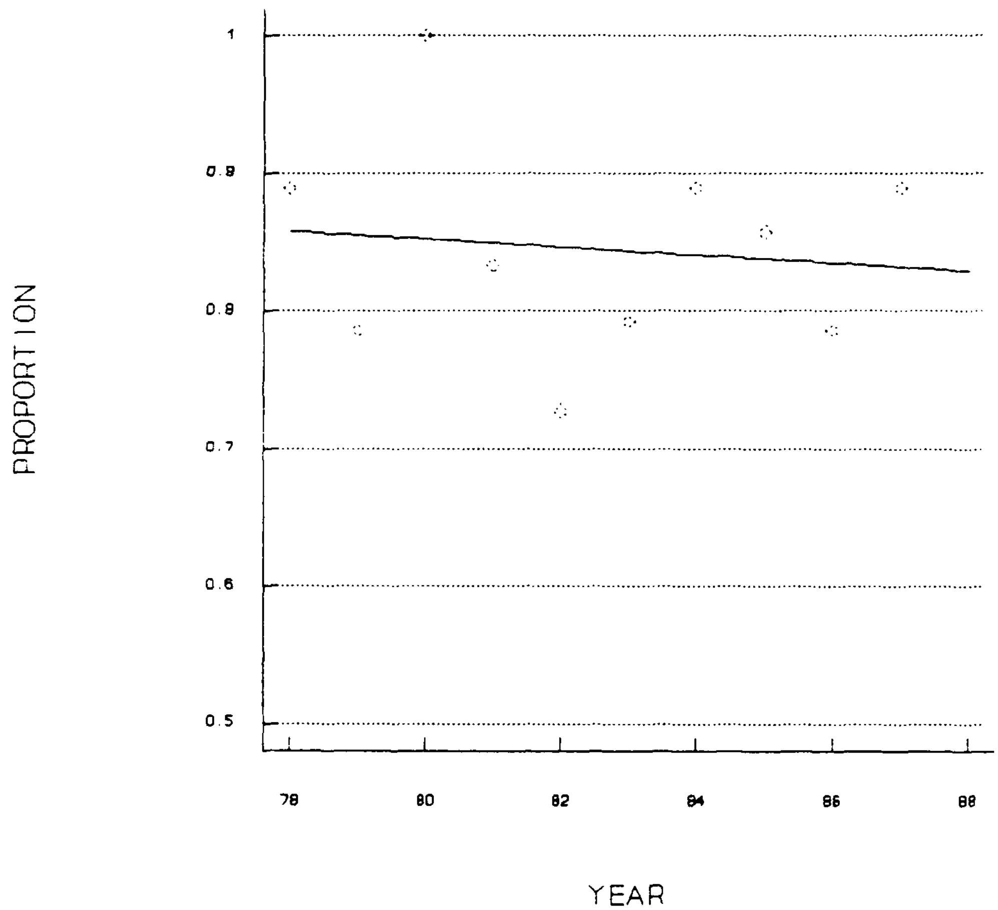

Figure 4: Figure 1 with Regression Line

TABLE 1. STATGRAF REGRESSION AND ANALYSIS OF VARIANCE TABLES

Regression Analysis - Linear model: Y = a+bX

Dependent variable: G.N163 Independent variable: G.YEAR

Parameter	Estimate	Standard Error	T Value	Prob. Level
Intercept	1.0858	0.740525	1.46626	.18075
Slope	-2.92121E-3	8.97062E-3	-0.325642	.75305

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Level
Model	.0007040	1	.0007040	.106043	.75305
Error	.0531116	8	.0066389		
Total (Corr.)	.0538156	9			

Correlation Coefficient = -0.114376 R-squared = 1.31 percent
Stnd. Error of Est. = 0.0814797

Following the validation of the assumption of independence, the ten observations of fraction retained & promoted were aggregated to provide a single point estimate of the probability of an officer from the class being retained & promoted. For ranks O4, O5, and O6, the point estimates for officers from each of the three sources were pooled because sufficient data were not available to develop accurate estimates without further aggregation.

Pooling of O4, O5, and O6 data is justified by the fact that differences in precommissioning programs of officers have very little impact on retention and promotion figures at the O4 and higher levels since these officers have received considerable amounts of identical training and similar experience since commissioning. Attempts to statistically justify the pooling using hypothesis tests of equal means were unsuccessful due to a lack of data, particularly for the officers from the NUPOC program. The final point estimate for each source and combination of years of service and rank was assigned to a parameter in GAMS labeled RAPMEAN(I,J,K). All values of RAPMEAN(I,J,K) and RNPMEAN(I,J,K) were derived in the manner described except those discussed in the next section.

2. Exceptions

The values assigned to RAPMEAN and RNPMEAN for O3's with eight or nine years of service are weighted averages of the values of the estimates for the officers from each of the three sources. The estimates for the officers from each source were pooled since only two years of representative data were available. Following 1985, a shift in policy resulted in the majority of promotions from O3 to O4 occurring following nine years of service, rather than eight. Thus, only 1986 and 1987 values were used in obtaining a point estimate representative of current promotion policy, and the estimates for the officers from each source were aggregated to provide a single estimate with a reasonable degree of accuracy.

3. Variance Estimation

The variance of the estimator $\hat{p}$ is given by

$$\frac{p(1-p)}{n}$$

and is estimated by

$$\frac{\hat{p}(1-\hat{p})}{n} .$$

As previously mentioned, no a priori knowledge of n exists. To produce a reasonable estimate of the variance of $\hat{p}$, it is assumed that the actual number of trials (officers to be considered for retention and promotion) will be considerably less than the number, say n', used to calculate $\hat{p}$. In fact, it is assumed that the number of trials will be one-tenth the number of trials used in calculating $\hat{p}$, since ten years of data were included. There is no reason to believe that n'/10 represents the mean of the distribution of n, but it should be much closer to the mean than is n'. Thus, the problem of underestimating the variance of $\hat{p}$ is resolved by using

$$\frac{\hat{p}(1-\hat{p})}{(n'/10)}$$

rather than

$$\frac{\hat{p}(1-\hat{p})}{n'}$$

as the estimator.

C. COSTS

1. Precommissioning Cost

The cost of producing a commissioned officer was analyzed for each commissioning source. Since data were provided independently by personnel representing each source, the ability to compare the data in detail is questionable.

However, since the costs of the three sources are so different, and no detailed cost analysis of the output was done, minor problems with the cost data had little effect on the results. The cost data for the NUPOC program was most questionable, since liaison officers at the program office were unable to provide historical data, but did provide rough estimates of various program administrative costs.

The estimate of the NUPOC program cost was combined with the historical cost data for Officer Candidate School (OCS), which NUPOC candidates must attend, to provide the precommissioning cost for the NUPOC program. In addition to OCS costs, the candidates' pay and an "admin" cost were estimated. The method used to estimate the cost of an entrant from the NUPOC program is described in Appendix B.

The historical data for the USNA, NROTC, and OCS were converted to constant 1988 dollars for analysis. The costs were plotted versus year, and simple linear regression analysis was performed. For each set of data, no real growth in cost is evident. (See Appendix B for ANOVA tables and regression plots.) Therefore, program costs were modeled as constants, equal to the mean value of their historical costs expressed in 1988 dollars.

2. Postcommissioning Cost

Since the model requires only costs that vary depending on the commissioning source of an officer, postcommissioning cost consists only of an annualized base pay calculated from the 1988 monthly base pay table. The only difference in the postcommissioning costs of officers from the three sources is due to NUPOC officers being credited for pay purposes for their years in the NUPOC program prior to commissioning. For example, an O3 from the NUPOC (two year) program with five years of service is paid as an O3 with seven years of service, making NUPOC officers more costly, after commissioning, than USNA or NROTC officers. A description of the methods used to calculate annual costs is given in Appendix B.

D. OTHER INPUT DATA

1. Upper Bound on Accessions

The number of entrants from a commissioning source (I) in a year (L) is limited in the linear program by the supply constraints, equation (2), to be less than or equal to the maximum allowable number of accessions, denoted as M(I,L) in the model. Values assigned to M(I,L) can be varied in order to analyze the effects of changing recruiting quotas or commissioning source size. The initial values, M(I,'1988'), were set equal to the number of entrants from each source, I, in 1988. Growth, shrinkage, or stability in a commissioning source's size can also be modelled by controlling M(I,L).

2. Initial Manning Levels

The number of officers from each commissioning source in each rank and with less than seven years of service in 1988, was treated as input data since these officers will potentially compete for the same billets as the officers who will enter the program during 1989 through 1993. These data were taken from the files provided by DMDC and are included in the GAMS program listing in Appendix A.

IV. DEMONSTRATION OF MODEL APPLICATIONS

This chapter illustrates the effect and applications of the simulation/optimization (SIMOP) model. The first section demonstrates the difference between the solutions from the SIMOP model and the traditional (deterministic) optimization model in which all random inputs are replaced by the sample means (point estimates). The remaining sections give examples illustrating possible statistical output analyses. This set of examples is meant to motivate typical analysis involved in decision making and is by no means a complete demonstration of all possible uses of the model. The mean number of entrants from each source for each run of the model is listed in Appendix C.

A. RANDOM VERSUS DETERMINISTIC INPUT

In this section, the total program cost from the SIMOP runs are contrasted with the total program cost obtained from the deterministic optimization model. In the optimization model, the inputs for the proportions of officers retained & promoted (RAP) and retained & not promoted (RNP) are assumed deterministic and taken to be the point estimates of the true values. The resulting linear program was solved to obtain a minimum total cost of $94.6M. The corresponding SIMOP model was run twice with 150 replications per run. The results from these two runs are summarized in the form of 95% confidence intervals for the total program cost and tabulated, with the result for the optimization (fixed input) model, in Table 2.

TABLE 2.
COMPARISON OF RANDOM RUNS VS.
RUN WITH DETERMINISTIC INPUT

Run	95% Confidence Interval		Mean Total Cost
	Lower Bound	Upper Bound	
Random 1 Random 2	86.5M 86.4M	91.7M 88.7M	89.1M 87.6M
Fixed	Total Cost = 94.6M		

The confidence intervals are calculated based on the assumption that the "random" total program cost generated by the SIMOP model is from a normal population. This assumption is confirmed using the Kolmogorov-Smirnov goodness-of-fit test. The frequency histogram of the total program cost from the model is depicted in Figure 5 and verifies visually the result of the Kolmogorov-Smirnov test.

From Table 2, it is clear that neither of the two confidence intervals include the total program cost from the deterministic optimization model. A statistical test leads to the rejection of the hypothesis that the mean total program cost from the SIMOP model is equal to the total program cost from the deterministic model (at level $\alpha = 0.05$).

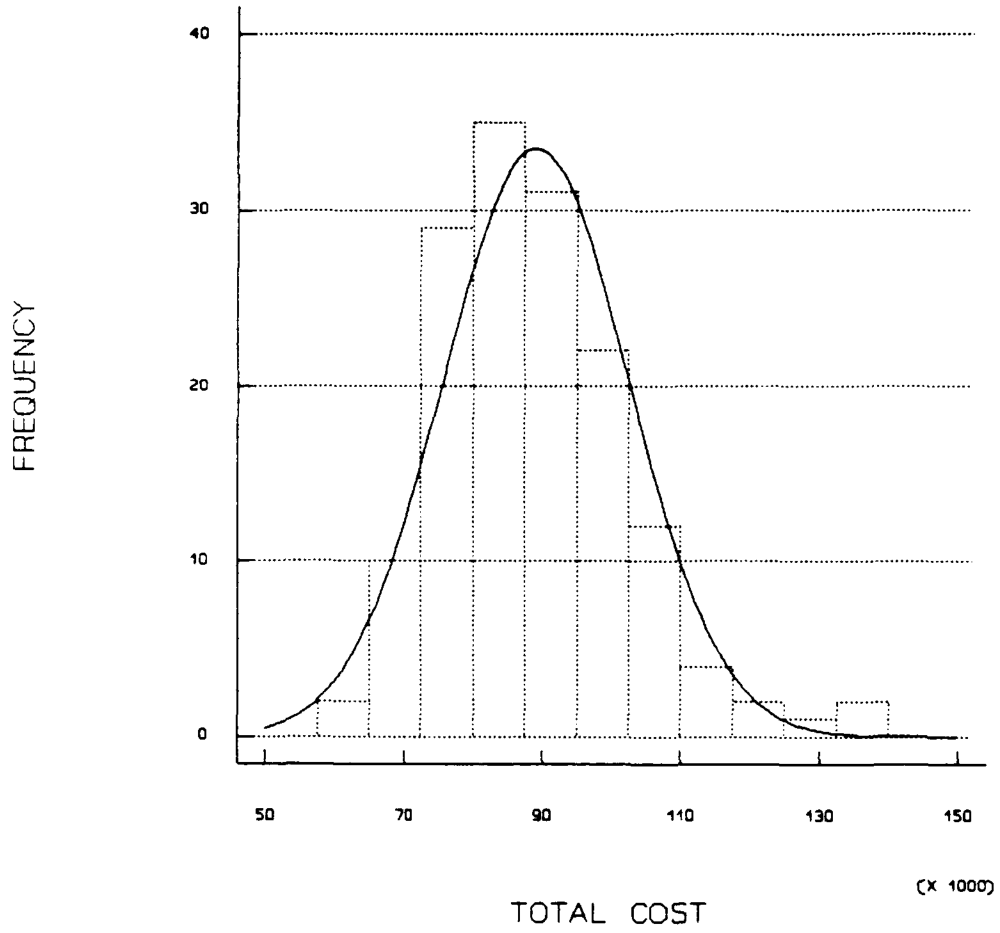

Figure 5: Frequency Histogram of Total Cost

It is common knowledge that if X_1, X_2, ..., X_n are random variables, independent or otherwise, then

$$E[C_1X_1 + C_2X_2 +...+ C_nX_n] = C_1E[X_1] + C_2E[X_2] +...+ C_nE[X_n].$$

Based on this result and the fact that both the objective function and the constraints are linear functions of random variables, one might be led to believe that solving the deterministic optimization model using the point estimates would produce a solution which is approximately the mean of the output from the SIMOP model. However, the results summarized in Table 2 empirically demonstrate otherwise. This is true since, in linear programming, the optimal objective function value varies in a piece-wise linear fashion with respect to the values of the available resources and the coefficients defining the constraints.

B. UP-DETAILING POLICY

A set of five runs, with thirty replications per run, was performed to demonstrate the use of the model for comparing various up-detailing policies. As mentioned in Chapter II, there are insufficient numbers of O4 officers in the fleet to fill all O4 billets. In order to fill all O4 billets, up-detailing is employed. Up-detailing normally involves filling billets with officers of rank lower than is specified for the billets. For example, some O4 billets may be filled by senior O3s. In this section, the SIMOP model is used to examine the effect on the total program cost of five different up-detailing policies. The policies examined may or may not represent acceptable up-detailing policies, but suffice as examples.

Policy 1: No up-detailing is allowed.

Policy 2: O3s with nine years of service are used to fill O4 billets.

Policy 3: O3s with eight or nine years of service are used to fill O4 billets.

Policy 4: Half of O3s with eight years of service and three-quarters of O3s with nine years of service are used to fill O4 billets.

Policy 5: Half of O3s with eight years of service and all O3s with nine years of service are used to fill O4 billets.

For each of the five policies, a run of the SIMOP model with thirty replications was conducted and the resulting confidence intervals on total program cost are given in Table 3. Note that only thirty replications were performed since for samples of this size the sample standard deviation will be very close to the standard deviation of the population, and thus the Central Limit Theorem prevails [Ref. 5:p. 210].

TABLE 3.
CONFIDENCE INTERVALS ON TOTAL COST
FOR DIFFERENT UP-DETAILING POLICIES

Run	95% Confidence Interval		Mean Total Cost
	Lower Bound	Upper Bound	
Policy 1	115.9M	127.4M	121.7M
Policy 2	95.0M	105.9M	100.5M
Policy 3	78.3M	87.6M	83.0M
Policy 4	87.6M	98.6M	93.1M
Policy 5	84.6M	94.9M	89.8M

From Table 3, it may be hypothesized, for example, that Policy 4 results in a lower mean total cost than does Policy 2. Through the use of common statistical hypothesis testing, this type of hypothesis can be tested. For this example, one would reject (at level $\alpha = 0.05$) the null hypothesis that the mean total cost for Policies 2 and 4 are equal and conclude that the total program cost is lower when Policy 4 is used.

For the purpose of demonstrating possible uses of the model, up-detailing policy number four is assumed for the remaining examples.

C. CONFIDENCE INTERVAL ON TOTAL COST

This section demonstrates the ability to estimate the total cost for a policy over the next five fiscal years within a specified level of accuracy. This type of analysis may be required, for example, in five year budget planning. For this demonstration, a confidence interval half-width of \$2.5M and confidence level of 98% were arbitrarily chosen. Thus the planner can be sure that the true mean (for this model) lies within a \$5M range with probability 0.98. Given an estimate of variance, the required number of replications is approximated by

$$n \approx \frac{(z_{0.98})^2 \cdot \hat{\sigma}^2}{A^2}$$

where n = the required number of replications,

$z_{0.98}$ = the standard normal value associated with the 98th percentile,

A = the interval half-width,

and $\hat{\sigma}^2$ = an estimate of variance.

This method of approximating the required number of replications (i.e. assuming that the confidence interval statistic has a normal distribution) is often recommended by statisticians when n is greater than or equal to thirty. It is justified by the presumption that for large samples, $\hat{\sigma}^2$ will be close to σ^2 and thus the Central Limit Theorem prevails [Ref. 5:pp. 240-241].

For this case, $\hat{\sigma}^2$ was assigned the sample variance obtained from a run with thirty replications. The confidence interval on total cost and the confidence interval half-width are (\$86.5M, 91.7M) and \$2.6M, respectively. Note that due to having estimated the variance, and thus the required number of runs, this interval is slightly larger than was originally desired. If necessary, the interval could be made smaller by performing additional replications and pooling the new results with those previously obtained.

D. NUPOC PROGRAM COST

As noted in Section C of Chapter III, the cost of the NUPOC program, excluding OCS costs, was not as accurately determined as the costs of the other programs. To examine the sensitivity of the total cost to changes in cost of the NUPOC program, three runs, each of thirty replications, were performed. The first run assumes that the cost of the NUPOC program is as obtained in Section C of Chapter III, which is referred to as the "original cost" (OC). The second run assumes that the NUPOC program costs only half the original cost (½ · OC), and the third assumes that it costs twice the original cost (2 · OC). Table 4 provides the confidence intervals for the three runs.

TABLE 4.
CONFIDENCE INTERVALS ON TOTAL COST
FOR VARYING NUPOC PROGRAM COSTS

Run	95% Confidence Interval		Mean Total Cost
	Lower Bound	Upper Bound	
½ · OC	86.6M	97.3M	92.0M
OC	87.6M	98.7M	93.2M
2 · OC	89.0M	100.8M	94.9M

Let μ_h, μ_o, and μ_t denote the mean total program cost when the NUPOC program costs half the original cost, the original cost, and twice the original cost, respectively. The following hypothesis test was conducted at level $\alpha = 0.05$:

$$H_0: \quad \mu_h = \mu_t$$
$$H_1: \quad \mu_h \neq \mu_t \ .$$

The test resulted in a failure to reject the null hypothesis. Since $\mu_h \leq \mu_o \leq \mu_t$, the above test is sufficient to show that there is no statistically significant difference among the three means. Thus, for this example, total cost is relatively insensitive to NUPOC program cost within the range examined. Therefore, a planner might conclude that effort would be better spent attempting to reduce cost in areas other than the NUPOC precommissioning program.

E. EFFECTS OF SOURCE SIZE

To demonstrate the use of the model to explore program policies concerning commissioning source size, the model was run with the maximum number of entrants from the NROTC program held constant at thirty-five. Because the entrants to the nuclear trained surface warfare officer community from the USNA or NROTC programs come from a "general" pool of officer candidates in these programs, the number of entrants from these programs may not be controlled as well as the community manpower planners might like. For this example, assume that the number of entrants from the NROTC program is proportional to the total size of the NROTC program, and that the "controller" of the NROTC program has frozen the size of the program due to budgetary constraints.

The question then is, "What effect will freezing the maximum number of entrants from the NROTC program (at 35 for this example) have on total cost?" The results of this run were compared with the base run in which each of the three source programs were allowed to grow. The comparison is summarized in Table 5.

TABLE 5.
CONFIDENCE INTERVALS ON TOTAL COST
FOR DIFFERENT NROTC PROGRAM SIZES

Run	95% Confidence Interval		Mean Total Cost
	Lower Bound	Upper Bound	
Base	87.6M	98.7M	93.2M
Only 35	94.2M	106.3M	100.3M

Again, a hypothesis test was conducted at level $\alpha = 0.05$,

$$H_0: \quad \mu_b = \mu_{35}$$
$$H_1: \quad \mu_b < \mu_{35} \quad ,$$

where μ_b and μ_{35} denote the mean total cost of the base run and the run in which the maximum number of entrants from the NROTC program is 35, respectively. For this test, the null hypothesis is rejected, and a manpower planner could conclude that the total cost would be higher if the number of entrants from the NROTC program were restricted to thirty-five.

V. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

This thesis examines a nontraditional approach to a manpower planning problem. This approach combines two operations research methodologies: simulation and optimization. The combined approach, which is referred to as SIMOP, models the manpower planning problem as a linear program and, through simulation techniques, allows the input data to be random. As discussed in Chapter I, either a linear programming model with deterministic data or a Markov Chain model with known transition probabilities has been considered in many manpower studies. Because the expected value of the sum of random variables is equal to the sum of expected values, it can be mistakenly concluded that the result from the deterministic linear programming model approximates the one from SIMOP. However, the experiments in Chapter IV empirically indicate that the relationship between the coefficients defining the constraints and the corresponding optimal solution is nonlinear. In addition, the difference between the solutions from SIMOP and the optimization model is statistically significant. Several examples in Chapter IV also demonstrate that the SIMOP process is a viable alternative in manpower studies.

B. FURTHER STUDIES RECOMMENDED

1. Additional Modeling Efforts

In this study, the base runs allowed the source programs to grow by fifteen percent each year, and it was assumed that all candidates who entered the program successfully completed all training requirements and a first year of duty. A more realistic model would incorporate the anticipated number of volunteers from each source and allow for 1) the screening of applicants from the sources, 2) attrition prior to commissioning, and 3) attrition in the training pipeline.

In addition, further work in modeling the retention and promotion rates is recommended. Bunn addresses Bayesian updating with continuous prior distributions and the relationship between the Binomial and Beta Distributions [Ref. 6]. The suitability of the Beta Binomial Distribution in the modeling of the promotion and retention of officers merits further investigation.

2. Critical Values of Retention and Promotion

The number of entrants from a source in a given year varied widely depending on whether or not it was the "preferred" source (i.e. depending on the combined effects of cost and retention and promotion rates). Hypothetically, there are critical stages in career development and critical values of promotion and retention rates that will determine whether or not the source is the preferred source. An in-depth sensitivity analysis is suggested in order to identify these critical values. Knowledge of the critical values in question might serve to better mold future retention and promotion policies and goals.

3. Use of Elasticity of Supply and Variable Bonus

Given a measure of the elasticity of supply for entrants to the nuclear trained surface warfare officer community, the model could be used to determine proper levels at which to set a variable (by source) accession bonus. Consider the following example. Assume that USNA officers are more cost effective than either NROTC or NUPOC officers, but the anticipated availability of volunteers from the USNA are less than the desired number of entrants. Given the elasticity of supply for the USNA graduates, it would be possible to determine the accession bonus (for the USNA graduates) that would induce the desired number of USNA volunteers. However, the USNA officers would now cost more due to the added bonus cost, and the desired number of entrants from the USNA will have changed. This problem could be solved by modifying the model from this study and solving it as a nonlinear program. This type of program is inherently more difficult to solve, but would provide very useful data if future shortages of volunteers were anticipated.

APPENDIX A: GAMS PROGRAM LISTING

```
$OFFSYMLIST OFFSYMXREF
OPTIONS DECIMALS=2, LIMCOL=0, LIMROW=0, SOLPRINT=OFF;

SETS
   I     source            /USNA,NROTC,NUPOC/
   J     years of service  /0*24/
   K     military rank     /01*06/
   L     year              /1988*2017/
   NITER dummy set         /I1*I100/
   NLOOP number of runs    /N1*N150/

*DATA
   TABLE POSS(J,K,L)    *  1 if years of service J, rank K and year L
                        *  are compatible
          1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998
   0.01
   1.01     1    1    1    1    1    1    1    1    1    1    1
   2.02     1    1    1    1    1    1    1    1    1    1    1
   3.02     1    1    1    1    1    1    1    1    1    1    1
   4.03     1    1    1    1    1    1    1    1    1    1    1
   5.03     1    1    1    1    1    1    1    1    1    1    1
   6.03     1    1    1    1    1    1    1    1    1    1    1
   7.03          1    1    1    1    1    1    1    1    1    1
   8.03               1    1    1    1    1    1    1    1    1
   8.04               1    1    1    1    1    1    1    1    1
   9.03                    1    1    1    1    1    1    1    1
   9.04                    1    1    1    1    1    1    1    1
  10.04                         1    1    1    1    1    1    1
  11.04                              1    1    1    1    1    1
  12.04                                   1    1    1    1    1
  13.04                                        1    1    1    1
  14.04                                             1    1    1
  15.04                                                  1    1
  15.05                                                       1
  16.05
  17.05
  18.05
  19.05
  19.06
  20.05
  20.06
  21.05
  21.06
  22.06
  23.06
```

24.06 +	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
0.01											
1.01	1	1	1								
2.02	1	1	1	1							
3.02	1	1	1	1	1						
4.03	1	1	1	1	1	1					
5.03	1	1	1	1	1	1	1				
6.03	1	1	1	1	1	1	1	1			
7.03	1	1	1	1	1	1	1	1	1		
8.03	1	1	1	1	1	1	1	1	1		
8.04	1	1	1	1	1	1	1	1	1	1	
9.03	1	1	1	1	1	1	1	1	1	1	
9.04	1	1	1	1	1	1	1	1	1	1	
10.04	1	1	1	1	1	1	1	1	1	1	1
11.04	1	1	1	1	1	1	1	1	1	1	1
12.04	1	1	1	1	1	1	1	1	1	1	1
13.04	1	1	1	1	1	1	1	1	1	1	1
14.04	1	1	1	1	1	1	1	1	1	1	1
15.04	1	1	1	1	1	1	1	1	1	1	1
15.05	1	1	1	1	1	1	1	1	1	1	1
16.05	1	1	1	1	1	1	1	1	1	1	1
17.05		1	1	1	1	1	1	1	1	1	1
18.05			1	1	1	1	1	1	1	1	1
19.05				1	1	1	1	1	1	1	1
19.06					1	1	1	1	1	1	1
20.05					1	1	1	1	1	1	1
20.06						1	1	1	1	1	1
21.05						1	1	1	1	1	1
21.06							1	1	1	1	1
22.06								1	1	1	1
23.06									1	1	1
24.06										1	1

+	2010	2011	2012	2013	2014	2015	2016	2017
0.01								
1.01								
2.02								
3.02								
4.03								
5.03								
6.03								
7.03								
8.03								
8.04								
9.03								
9.04								
10.04								
11.04	1							
12.04	1	1						
13.04	1	1	1					
14.04	1	1	1	1				
15.04	1	1	1	1				
15.05	1	1	1	1	1			
16.05	1	1	1	1	1			
17.05	1	1	1	1	1	1		
18.05	1	1	1	1	1	1	1	
19.05	1	1	1	1	1	1	1	
19.06	1	1	1	1	1	1	1	1
20.05	1	1	1	1	1	1	1	
20.06	1	1	1	1	1	1	1	1
21.05	1	1	1	1	1	1	1	
21.06	1	1	1	1	1	1	1	1
22.06	1	1	1	1	1	1	1	1
23.06	1	1	1	1	1	1	1	1
24.06	1	1	1	1	1	1	1	1 ;

```
TABLE BR(K,L)   *  number of rank K billets to be filled in year L
        1989  1990  1991  1992  1993  1994  1995  1996  1997  1998
01            23    23    23    23    23
02                  111   111   111   111   111   111
03                              61    61    61    61    61    61
04                                                      97    97
05
06

 +      1999  2000  2001  2002  2003  2004  2005  2006  2007  2008
01
02
03       61    61    61    61
04       97    97    97    97    97    97    97    97    97    97
05                                     35    35    35    35    35
06                                                             20
 +      2009  2010  2011  2012  2013  2014  2015  2016  2017
01
02
03
04
05       35    35    35    35    35    35
06       20    20    20    20    20    20    20    20    20;

PARAMETERS BR12(L),     *  number of O1 and O2 billets to be filled
                        * in year L
       BR3(L),          *  number of O3 billets to be filled in year L
       BR4(L),          *  number of O4 billets to be filled in year L
       BR5(L),          *  number of O5 billets to be filled in year L
       BR6(L);          *  number of O6 billets to be filled in year L

        BR12(L) = BR('O1',L) + BR('O2',L);
        BR3(L)  = BR('O3',L);
        BR4(L)  = BR('O4',L);
        BR5(L)  = BR('O5',L);
        BR6(L)  = BR('O6',L);

PARAMETERS NUPOC3,    *  proportion of NUPOC candidates who enter
       NUPOC2,        *  the program with three (NUPOC3), two (NUPOC2),
       NUPOC1,        *  or one (NUPOC1) year of college remaining or
       NUPOC0;        *  after graduation from college (NUPOC0)

       NUPOC3 = 0.000;
       NUPOC2 = 0.333;
       NUPOC1 = 0.333;
       NUPOC0 = 0.333;
```

```
PARAMETERS E3,          *  monthly base pay for E3 with less than 2
                        *   years of service
       E4,              *  monthly base pay for E4 with less than 2
                        *   years of service
       E5,              *  monthly base pay for E5 with less than 2
                        *   years of service
       E52,             *  monthly base pay for E5 with more than 2
                        *   years of service
       ADMIN;           *  estimated administrative cost of a
                        *   NUPOC commissionee

       E3    =  814.20;
       E4    =  864.30;
       E5    =  926.70;
       E52   = 1008.60;
       ADMIN = 5000.00;

PARAMETER OCSCOST;      *  cost of the OCS commissioning program
       OCSCOST = 18590;

PARAMETER PRECOST(I,L);          *  cost of an officer from source I
                                 *   in year L

       PRECOST('USNA',L) = 162581;
       PRECOST('NROTC',L) = 53995;
       PRECOST('NUPOC',L) = NUPOC2*(12*E3 + 12*E4 + 5*E52)
           + NUPOC1*(12*E4 + 5*E5) + NUPOC0*(5*E5) + ADMIN + OCSCOST;
       PRECOST(I,L) = PRECOST(I,L)/1000;
```

```
TABLE MOCOST(J,K)      *  monthly base pay for rank K and years of
                        *  service J
        01      02      03      04      05      06
  0   1339
  1   1339
  2   1394    1685
  3   1685    2024
  4           2092    2339
  5           2092    2339
  6                   2451
  7                   2451
  8                   2539    2629
  9                   2539    2629
 10                   2676    2809
 11                   2676    2809
 12                           2966
 13                           2966
 14                           2472
 15                           2472    3284
 16                           3238    3530
 17                           3238    3530
 18                           3328    3732    4160
 19                                   3732    4160
 20                                   3845    4250
 21                                   3845    4250
 22                                   3979    4497
 23                                   3979    4497
 24                                           4497 ;

PARAMETER POSTCOST(I,J,K);        *  cost of an officer from source I,
                                   *  with rank K and J years of service
      POSTCOST(I,J,K) = MOCOST(J,K);
      POSTCOST('NUPOC',J,K)$(ORD(J) LE 23)
              = NUPOC2*POSTCOST('NUPOC',J+2,K)
              + NUPOC1*POSTCOST('NUPOC',J+1,K)
              + NUPOC0*POSTCOST('NUPOC',J,K);
      POSTCOST('NUPOC','23','06') = 4497;
      POSTCOST('NUPOC','24','06') = NUPOC2*4877 + (1-NUPOC2)*4497;
      POSTCOST(I,J,K) = (12*POSTCOST(I,J,K)/1.041)/1000;

PARAMETER M(I,L);              *  maximum number of entrants form source
                                *  I in year L
      M('USNA','1988')  = 45;
      M('NROTC','1988') = 31;
      M('NUPOC','1988') = 35;
      LOOP(L$(ORD(L) LT 14),   M(I,L+1) = MIN(250, 1.15*M(I,L));  );

PARAMETER RNPMEAN(I,J,K)      *  point estimate of proportion of
                             *  officers in class I,J,K that is
     /USNA . 0.01  1.000      *  retained & not promoted
      NROTC. 0.01  1.000
```

NUPOC.	0.01	1.000
USNA .	2.02	0.941
NROTC.	2.02	0.976
NUPOC.	2.02	0.928
USNA .	4.03	0.622
NROTC.	4.03	0.640
NUPOC.	4.03	0.528
USNA .	5.03	0.748
NROTC.	5.03	0.798
NUPOC.	5.03	0.741
USNA .	6.03	0.865
NROTC.	6.03	0.794
NUPOC.	6.03	0.813
USNA .	7.03	0.746
NROTC.	7.03	0.778
NUPOC.	7.03	0.526
USNA .	8.03	0.754
NROTC.	8.03	0.754
NUPOC.	8.03	0.754
USNA .	8.04	1.000
NROTC.	8.04	1.000
NUPOC.	8.04	1.000
USNA .	9.04	0.942
NROTC.	9.04	0.942
NUPOC.	9.04	0.942
USNA .	10.04	0.884
NROTC.	10.04	0.884
NUPOC.	10.04	0.884
USNA .	11.04	0.938
NROTC.	11.04	0.938
NUPOC.	11.04	0.938
USNA .	12.04	0.933
NROTC.	12.04	0.933
NUPOC.	12.04	0.933
USNA .	13.04	0.775
NROTC.	13.04	0.775
NUPOC.	13.04	0.775
USNA .	14.04	0.125
NROTC.	14.04	0.125
NUPOC.	14.04	0.125
USNA .	15*16.05	1.000
NROTC.	15*16.05	1.000
NUPOC.	15*16.05	1.000
USNA .	17.05	0.955
NROTC.	17.05	0.955
NUPOC.	17.05	0.955
USNA .	18.05	0.875
NROTC.	18.05	0.875
NUPOC.	18.05	0.875
USNA .	19.05	0.710
NROTC.	19.05	0.710

```
          NUPOC.19.05  0.710
          USNA .20.05  0.167
          NROTC.20.05  0.167
          NUPOC.20.05  0.167
          USNA .19*20.06  1.000
          NROTC.19*20.06  1.000
          NUPOC.19*20.06  1.000
          USNA .21.06  0.975
          NROTC.21.06  0.975
          NUPOC.21.06  0.975
          USNA .22.06  0.976
          NROTC.22.06  0.976
          NUPOC.22.06  0.976
          USNA .23.06  0.957
          NROTC.23.06  0.957
          NUPOC.23.06  0.957/;

PARAMETER RAPMEAN(I,J,K)          *  point estimate of proportion of
                                * officers in class I,J,K that is
        /USNA . 1.01  0.937        *  retained & promoted
         NROTC. 1.01  0.961
         NUPOC. 1.01  0.907
         USNA . 3.02  0.840
         NROTC. 3.02  0.734
         NUPOC. 3.02  0.355
         USNA . 7.03  0.094
         NROTC. 7.03  0.093
         NUPOC. 7.03  0.158
         USNA . 8.03  0.158
         NROTC. 8.03  0.158
         NUPOC. 8.03  0.158
         USNA . 9.03  0.893
         NROTC. 9.03  0.893
         NUPOC. 9.03  0.893
         USNA .14.04  0.806
         NROTC.14.04  0.806
         NUPOC.14.04  0.806
         USNA .15.04  0.125
         NROTC.15.04  0.125
         NUPOC.15.04  0.125
         USNA .18.05  0.078
         NROTC.18.05  0.078
         NUPOC.18.05  0.078
         USNA .19.05  0.161
         NROTC.19.05  0.161
         NUPOC.19.05  0.161
         USNA .20.05  0.738
         NROTC.20.05  0.738
         NUPOC.20.05  0.738
         USNA .21.05  0.500
         NROTC.21.05  0.500
```

```
        NUPOC.21.05  0.500/;

PARAMETER N(I,J,K)                    *  number of officers in class I,J,K
      /USNA . 1.01  143               *  from 1978 to 1987
       NROTC. 1.01  176
       NUPOC. 1.01  144
       USNA . 2.02  239
       NROTC. 2.02  208
       NUPOC. 2.02  165
       USNA . 3.02  282
       NROTC. 3.02  263
       NUPOC. 3.02  107
       USNA . 4.03  296
       NROTC. 4.03  175
       NUPOC. 4.03   53
       USNA . 5.03  194
       NROTC. 5.03  109
       NUPOC. 5.03   27
       USNA . 6.03  141
       NROTC. 6.03   68
       NUPOC. 6.03   16
       USNA . 7.03  138
       NROTC. 7.03   54
       NUPOC. 7.03   19
       USNA . 8.03   57
       NROTC. 8.03   57
       NUPOC. 8.03   57
       USNA . 9.03   28
       NROTC. 9.03   28
       NUPOC. 9.03   28
       USNA . 8.04   19
       NROTC. 8.04   19
       NUPOC. 8.04   19
       USNA . 9.04  121
       NROTC. 9.04  121
       NUPOC. 9.04  121
       USNA .10.04  138
       NROTC.10.04  138
       NUPOC.10.04  138
       USNA .11.04  113
       NROTC.11.04  113
       NUPOC.11.04  113
       USNA .12.04   90
       NROTC.12.04   90
       NUPOC.12.04   90
       USNA .13.04   89
       NROTC.13.04   89
       NUPOC.13.04   89
       USNA .14.04   72
       NROTC.14.04   72
       NUPOC.14.04   72
```

```
USNA .15.04     8
NROTC.15.04     8
NUPOC.15.04     8
USNA .15.05    60
NROTC.15.05    60
NUPOC.15.05    60
USNA .16.05    67
NROTC.16.05    67
NUPOC.16.05    67
USNA .17.05    66
NROTC.17.05    66
NUPOC.17.05    66
USNA .18.05    64
NROTC.18.05    64
NUPOC.18.05    64
USNA .19.05    62
NROTC.19.05    62
NUPOC.19.05    62
USNA .20.05    42
NROTC.20.05    42
NUPOC.20.05    42
USNA .21.05     6
NROTC.21.05     6
NUPOC.21.05     6
USNA .19.06     6
NROTC.19.06     6
NUPOC.19.06     6
USNA .20.06    16
NROTC.20.06    16
NUPOC.20.06    16
USNA .21.06    40
NROTC.21.06    40
NUPOC.21.06    40
USNA .22.06    41
NROTC.22.06    41
NUPOC.22.06    41
USNA .23.06    47
NROTC.23.06    47
NUPOC.23.06    47
USNA .24.06    37
NROTC.24.06    37
NUPOC.24.06    37/;

PARAMETERS NPQA(I,J,K), NPQN(I,J,K);    * parameter to determine mode
                                         * of random number generation
       NPQA(I,J,K)$N(I,J,K) =
                 N(I,J,K)*MIN(RAPMEAN(I,J,K),1-RAPMEAN(I,J,K));
       NPQN(I,J,K)$N(I,J,K) =
                 N(I,J,K)*MIN(RNPMEAN(I,J,K),1-RNPMEAN(I,J,K));
```

```
   PARAMETER VARN(I,J,K), VARA(I,J,K); * variance of the point estimates
          VARN(I,J,K)$(NPQN(I,J,K) GT 4.90)
                   = RNPMEAN(I,J,K)*(1-RNPMEAN(I,J,K))/N(I,J,K);
          VARA(I,J,K)$(NPQA(I,J,K) GT 4.90)
                   = RAPMEAN(I,J,K)*(1-RAPMEAN(I,J,K))/N(I,J,K);

   PARAMETERS RAP(I,J,K,L), RNP(I,J,K,L); *  the random proportions
          RAP(I,J,K,L) = 0.0;
          RNP(I,J,K,L) = 0.0;


   PARAMETER SFCOST;          *  cost of shortfall
          SFCOST = 10000;

   PARAMETERS Y1, Y2;         *  counters
          Y1 = 0;
          Y2 = 0;

   PARAMETERS ALLCOST(NLOOP,L),    *  collects total cost for each year
                                   *  after each run
          XUSNA(NLOOP,L),        *  collects number of entrants from USNA
          XNROTC(NLOOP,L),       *  collects number of entrants from NROTC
          XNUPOC(NLOOP,L);       *  collects number of entrants from NUPOC

   PARAMETERS EXCESS12(NLOOP,L), XSAVE12(L), XSVAR12(L),  *  collect
          EXCESS3(NLOOP,L), XSAVE3(L), XSVAR3(L),       *  statistics
         EXCESS4(NLOOP,L), XSAVE4(L), XSVAR4(L),       *  on number of
              EXCESS5(NLOOP,L), XSAVE5(L), XSVAR5(L),     *  entrants from
              EXCESS6(NLOOP,L), XSAVE6(L), XSVAR6(L),      *  each source
              XUSNAAVE(L), XUSNAVAR(L),                   *  and on amount
              XNROTAVE(L), XNROTVAR(L),                   *  of excess for
              XNUPOAVE(L), XNUPOVAR(L);                    *  each run

*VARIABLES
   POSITIVE VARIABLE   X(I,J,K,L), SF12(L),      *  the decision variables
           SF3(L), SF4(L), SF5(L), SF6(L);       *  for number of officers
                                                  *  in a class in year L
                                                 *  and amount of shortfall

   FREE VARIABLE  TOTAL;                         *  the variable to
                                                 *  minimize

   X.UP(I,J,K,L)$(POSS(J,K,L)) = 450;            *  upper bounds for the
   X.UP(I,'0','01',L)$(ORD(L) LT 14) = 450;      *  decision variables
   SF12.UP(L)$(BR12(L)) = 200;
   SF3.UP(L)$(BR3(L)) = 200;
   SF4.UP(L)$(BR4(L)) = 200;
   SF5.UP(L)$(BR5(L)) = 200;
   SF6.UP(L)$(BR6(L)) = 200;
```

```
*  ASSIGNMENT OF 1988 VALUES TO X
     X.FX(I,J,K,'1988')$(ORD(J) GT 1) = 0;
     X.FX('USNA' ,'0','01','1988') = 45;
     X.FX('NROTC','0','01','1988') = 31;
     X.FX('NUPOC','0','01','1988') = 35;
     X.FX('USNA' ,'1','01','1988') = 45;
     X.FX('NROTC','1','01','1988') = 31;
     X.FX('NUPOC','1','01','1988') = 35;
     X.FX('USNA' ,'2','02','1988') = 41;
     X.FX('NROTC','2','02','1988') = 30;
     X.FX('NUPOC','2','02','1988') = 31;
     X.FX('USNA' ,'3','02','1988') = 32;
     X.FX('NROTC','3','02','1988') = 29;
     X.FX('NUPOC','3','02','1988') = 52;
     X.FX('USNA' ,'4','03','1988') = 23;
     X.FX('NROTC','4','03','1988') = 41;
     X.FX('NUPOC','4','03','1988') = 21;
     X.FX('USNA' ,'5','03','1988') = 31;
     X.FX('NROTC','5','03','1988') = 18;
     X.FX('NUPOC','5','03','1988') =  4;
     X.FX('USNA' ,'6','03','1988') = 18;
     X.FX('NROTC','6','03','1988') = 25;
     X.FX('NUPOC','6','03','1988') =  6;


EQUATIONS          *  declaration of the equations
   OBJ
   DEMAND12(L)
   DEMAND3(L)
   DEMAND4(L)
   DEMAND5(L)
   DEMAND6(L)
   SUPPLY(I,L)
   NEXT01(I,J,K,L)
   NEXT0206(I,J,K,L);

   OBJ..                                          *  the objective function
     TOTAL =E= SUM((I,L)$(PRECOST(I,L) GT 0),
            PRECOST(I,L)*X(I,'0','01',L))
          +  SUM((I,J,K,L)$(POSS(J,K,L) AND (ORD(J) GT 1)),
            POSTCOST(I,J,K)*X(I,J,K,L))
          +  SFCOST*(SUM((L)$BR12(L), SF12(L)) + SUM((L)$BR3(L),
            SF3(L)) + SUM((L)$BR4(L), SF4(L)) + SUM((L)$BR4(L),
            SF5(L)) + SUM((L)$BR6(L), SF6(L)));

   DEMAND12(L)$(BR12(L))..                        *  demand for 01s and 02s
     SUM((I,J), X(I,J,'01',L)$POSS(J,'01',L)
      + X(I,J,'02',L)$POSS(J,'02',L)) + SF12(L) =G= BR12(L);

   DEMAND3(L)$(BR3(L))..                          *  demand for 03s
     SUM((I,J)$(ORD(J) LT  9), X(I,J,'03',L)$POSS(J,'03',L))
```

```
    + SUM((I), .5*X(I,'8','03',L)$POSS('8','03',L)
    + .25*X(I,'9','03',L)$POSS('9','03',L)) + SF3(L) =G= BR3(L);

DEMAND4(L)$(BR4(L))..                        *  demand for 04s
   SUM((I), .5*X(I,'8','03',L)$POSS('8','03',L)
    + .75*X(I,'9','03',L)$POSS('9','03',L))
    + SUM((I,J), X(I,J,'04',L)$POSS(J,'04',L)) + SF4(L) =G= BR4(L);

DEMAND5(L)$(BR5(L))..                        *  demand for 05s
   SUM((I,J), X(I,J,'05',L)$POSS(J,'05',L)) + SF5(L) =G= BR5(L);

DEMAND6(L)$(BR6(L))..                        *  demand for 06s
   SUM((I,J), X(I,J,'06',L)$POSS(J,'06',L)) + SF6(L) =G= BR6(L);

SUPPLY(I,L)$(ORD(L) LT 14)..                 *  supply limitations for
                                             *  each source
   X(I,'0','01',L) =L= M(I,L);

NEXT01(I,J+1,K,L+1)$((ORD(K) EQ 1) AND (POSS(J+1,K,L+1)))..
                                             *  converts 01s in year L
                                             *  to 01s in year L+1
   X(I,J+1,K,L+1) =E= RNP(I,J,K,L) * X(I,J,K,L);

NEXT0206(I,J+1,K+1,L+1)$POSS(J+1,K+1,L+1)..  *  converts officers from
                                             *  year L to officers in
                                             *  year L+1
   X(I,J+1,K+1,L+1) =E= RAP(I,J,K,L) * X(I,J,K,L) +
                        RNP(I,J,K+1,L) * X(I,J,K+1,L);
```

```
MODEL MANPOWER /ALL/;

LOOP(NLOOP,                 *  for each replication of the model
                           *  perform the following

*  random number generation using the normal approximation (truncated)
   RAP(I,J,K,L)$(VARA(I,J,K) AND POSS(J,K,L)) =
       MAX(MIN(NORMAL(RAPMEAN(I,J,K), SQRT(VARA(I,J,K))), 1.0), 0.0);
   RNP(I,J,K,L)$(VARN(I,J,K) AND POSS(J,K,L)) =
       MAX(MIN(NORMAL(RNPMEAN(I,J,K), SQRT(VARN(I,J,K))), 1.0), 0.0);

*  random number generation using the convolution method
   LOOP(I,
      LOOP(J,
         LOOP(K,
            LOOP(L$(POSS(J,K,L)),
               Y1 = 0;
               Y2 = 0;
               LOOP(NITER$
               ((ORD(NITER) LE ROUND(N(I,J,K)/10)) AND
                                                (VARA(I,J,K) EQ 0)),
                  Y1 = Y1 + 1$(UNIFORM(0,1) LE RAPMEAN(I,J,K));
               );
               RAP(I,J,K,L)$(Y1) = Y1/ROUND(N(I,J,K)/10);
               LOOP(NITER$((ORD(NITER) LE ROUND(N(I,J,K)/10))
                  AND (VARN(I,J,K) EQ 0) AND (RNPMEAN(I,J,K) NE 1.0)),
                  Y2 = Y2 + 1$(UNIFORM(0,1) LE RNPMEAN(I,J,K));
               );
               RNP(I,J,K,L)$(Y2) = Y2/ROUND(N(I,J,K)/10);
            );
         );
      );
   );

*  handling of special cases
   RNP(I,J,K,L)$((RNPMEAN(I,J,K) EQ 1.0) AND POSS(J,K,L))= 1.000;
   RNP(I,'0','01',L)$(ORD(L) LT 14) = 1.000;

*  the solve command
   SOLVE MANPOWER USING LP MINIMIZING TOTAL;

*  collection of statistics
   ALLCOST(NLOOP,L) = SUM((I)$(PRECOST(I,L) GT 0),
              PRECOST(I,L)*X.L(I,'0','01',L))
            +  SUM((I,J,K)$(POSS(J,K,L) AND (ORD(J) GT 1)),
              POSTCOST(I,J,K)*X.L(I,J,K,L))
            +  SFCOST*(SF12.L(L) + SF3.L(L) + SF4.L(L) +
              SF5.L(L) + SF6.L(L));
   EXCESS12(NLOOP,L) = DEMAND12.L(L) - BR12(L);
   EXCESS3(NLOOP,L) = DEMAND3.L(L) - BR3(L);
   EXCESS4(NLOOP,L) = DEMAND4.L(L) - BR4(L);
```

```
    EXCESS5(NLOOP,L) = DEMAND5.L(L) - BR5(L);
    EXCESS6(NLOOP,L) = DEMAND6.L(L) - BR6(L);
    XSAVE12(L) = XSAVE12(L) + EXCESS12(NLOOP,L);
    XSAVE3(L) = XSAVE3(L) + EXCESS3(NLOOP,L);
    XSAVE4(L) = XSAVE4(L) + EXCESS4(NLOOP,L);
    XSAVE5(L) = XSAVE5(L) + EXCESS5(NLOOP,L);
    XSAVE6(L) = XSAVE6(L) + EXCESS6(NLOOP,L);
    XUSNA(NLOOP,L)$(ORD(L) LE 6) = X.L('USNA','0','01',L);
    XUSNAAVE(L)$(ORD(L) LE 6) = XUSNAAVE(L) + XUSNA(NLOOP,L);
    XNROTC(NLOOP,L)$(ORD(L) LE 6) = X.L('NROTC','0','01',L);
    XNROTAVE(L)$(ORD(L) LE 6) = XNROTAVE(L) + XNROTC(NLOOP,L);
    XNUPOC(NLOOP,L)$(ORD(L) LE 6) = X.L('NUPOC','0','01',L);
    XNUPOAVE(L)$(ORD(L) LE 6) = XNUPOAVE(L) + XNUPOC(NLOOP,L);

*  calculation of averages
    XSAVE12(L) = XSAVE12(L)/CARD(NLOOP);
    XSAVE3(L) = XSAVE3(L)/CARD(NLOOP);
    XSAVE4(L) = XSAVE4(L)/CARD(NLOOP);
    XSAVE5(L) = XSAVE5(L)/CARD(NLOOP);
    XSAVE6(L) = XSAVE6(L)/CARD(NLOOP);
    XUSNAAVE(L)$(ORD(L) LE 6) = XUSNAAVE(L)/CARD(NLOOP);
    XNROTAVE(L)$(ORD(L) LE 6) = XNROTAVE(L)/CARD(NLOOP);
    XNUPOAVE(L)$(ORD(L) LE 6) = XNUPOAVE(L)/CARD(NLOOP);

*  calculation of variances
    XSVAR12(L) = SUM(NLOOP, SQR(EXCESS12(NLOOP,L) -
                        XSAVE12(L)))/(CARD(NLOOP)-1);
    XSVAR3(L) = SUM(NLOOP, SQR(EXCESS3(NLOOP,L) -
                        XSAVE3(L)))/(CARD(NLOOP)-1);
    XSVAR4(L) = SUM(NLOOP, SQR(EXCESS4(NLOOP,L) -
                        XSAVE4(L)))/(CARD(NLOOP)-1);
    XSVAR5(L) = SUM(NLOOP, SQR(EXCESS5(NLOOP,L) -
                        XSAVE5(L)))/(CARD(NLOOP)-1);
    XSVAR6(L) = SUM(NLOOP, SQR(EXCESS6(NLOOP,L) -
                        XSAVE6(L)))/(CARD(NLOOP)-1);
    XUSNAVAR(L)$(ORD(L) LE 6) = SUM(NLOOP, SQR(XUSNA(NLOOP,L) -
                        XUSNAAVE(L)))/(CARD(NLOOP)-1);
    XNROTVAR(L)$(ORD(L) LE 6) = SUM(NLOOP, SQR(XNROTC(NLOOP,L) -
                        XNROTAVE(L)))/(CARD(NLOOP)-1);
    XNUPOVAR(L)$(ORD(L) LE 6) = SUM(NLOOP, SQR(XNUPOC(NLOOP,L) -
                        XNUPOAVE(L)))/(CARD(NLOOP)-1);

*  display results
    DISPLAY ALLCOST, etc.;
                                    ); );
```

APPENDIX B: COST DETERMINATIONS

A. POSTCOMMISSIONING COSTS

Postcommissioning Costs for officers from the USNA and NROTC were determined by converting the 1989 monthly base pay to an annual figure. The annual figure was converted to the 1988 equivalent pay by dividing by 1.041 thus removing the effects of the 4.1% pay raise for 1989. Since officers from the NUPOC program receive credit for pay purposes for their time spent in the program (e.g. an O2 with three years of service who entered the program one year prior to commissioning gets paid as an O2 with four years of service), it was necessary to calculate their cost separately.

The NUPOC program is available to college students with one, two, or three years of school remaining, or to college graduates. The pay a candidate receives and the pay an officer from the NUPOC program receives depends on when in his education he joined the NUPOC program. Because no information was available on when candidates are likely to enter the program, an equal likelihood was assumed for two year, one year, and graduate entries. (An oversight led to the assignment of zero likelihood that candidates will enter with three years of college remaining.) Thus the postcommissioning cost of an officer from the NUPOC program was assumed to be the average of the annualized pays for three groups: officers who entered the program two years prior to graduation, officers who entered one year prior to graduation, and officers who entered after graduation from college.

B. PRECOMMISSIONING COSTS

Precommissioning costs for the USNA, OCS, and NROTC programs were based on averages over the data available since regression analysis showed statistically insignificant trends (real dollar changes) with respect to time or provided poor models of the data. For example, for USNA cost, a downward trend is indicated by the regression plot, but one would fail to reject (at level $\alpha = 0.05$) the hypothesis that the slope of the regression line is zero. Regression plots and associated regression and analysis of variance (ANOVA) tables for each analysis are shown on the pages following this section. The cost of OCS was summed with other NUPOC program costs to obtain a final NUPOC precommissioning cost.

Other NUPOC program costs included candidate pay and administrative costs. Candidate pay, as noted in the previous section, depends on when, in relation to graduation, a candidate enters the program. An average value of the total costs for each of the three cases considered (candidate enters with two years or one year of college remaining or after graduation) was used to represent the candidate pay portion of NUPOC program cost. The administrative cost, which includes costs for travel for interviews, ship visits, and paperwork, was estimated to be five thousand dollars per commissionee.

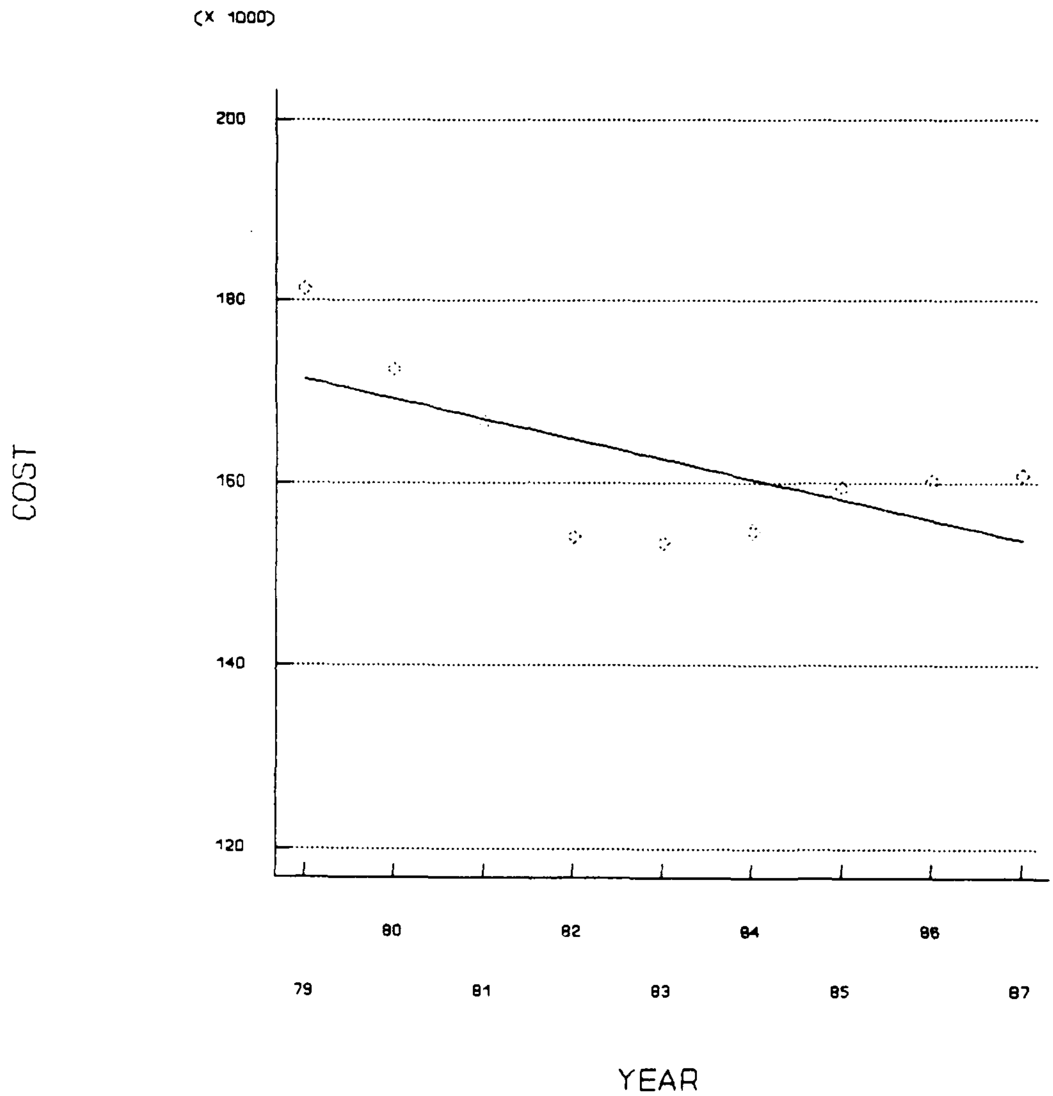

Figure 4: Regression of USNA Cost on Year

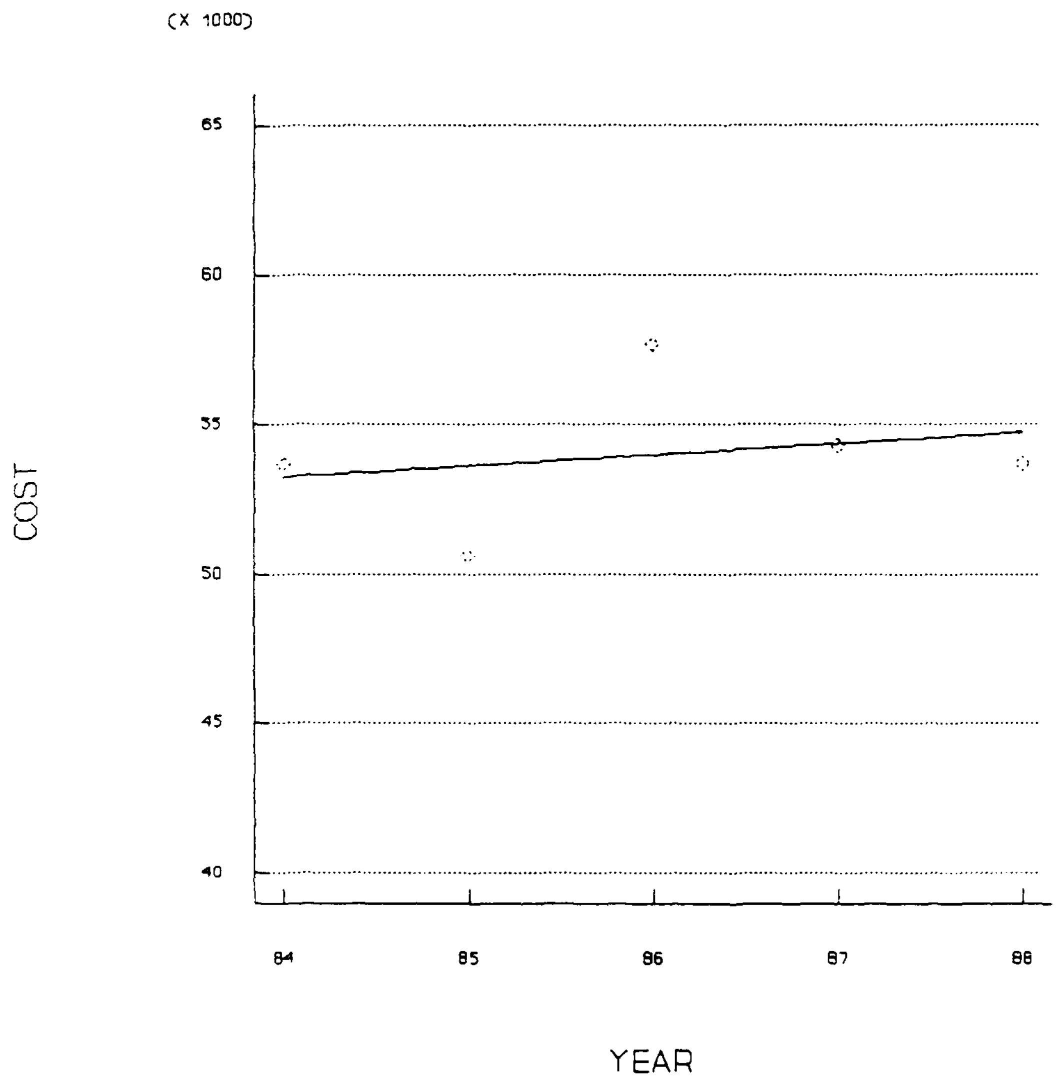

Figure 5: Regression of NROTC Cost on Year

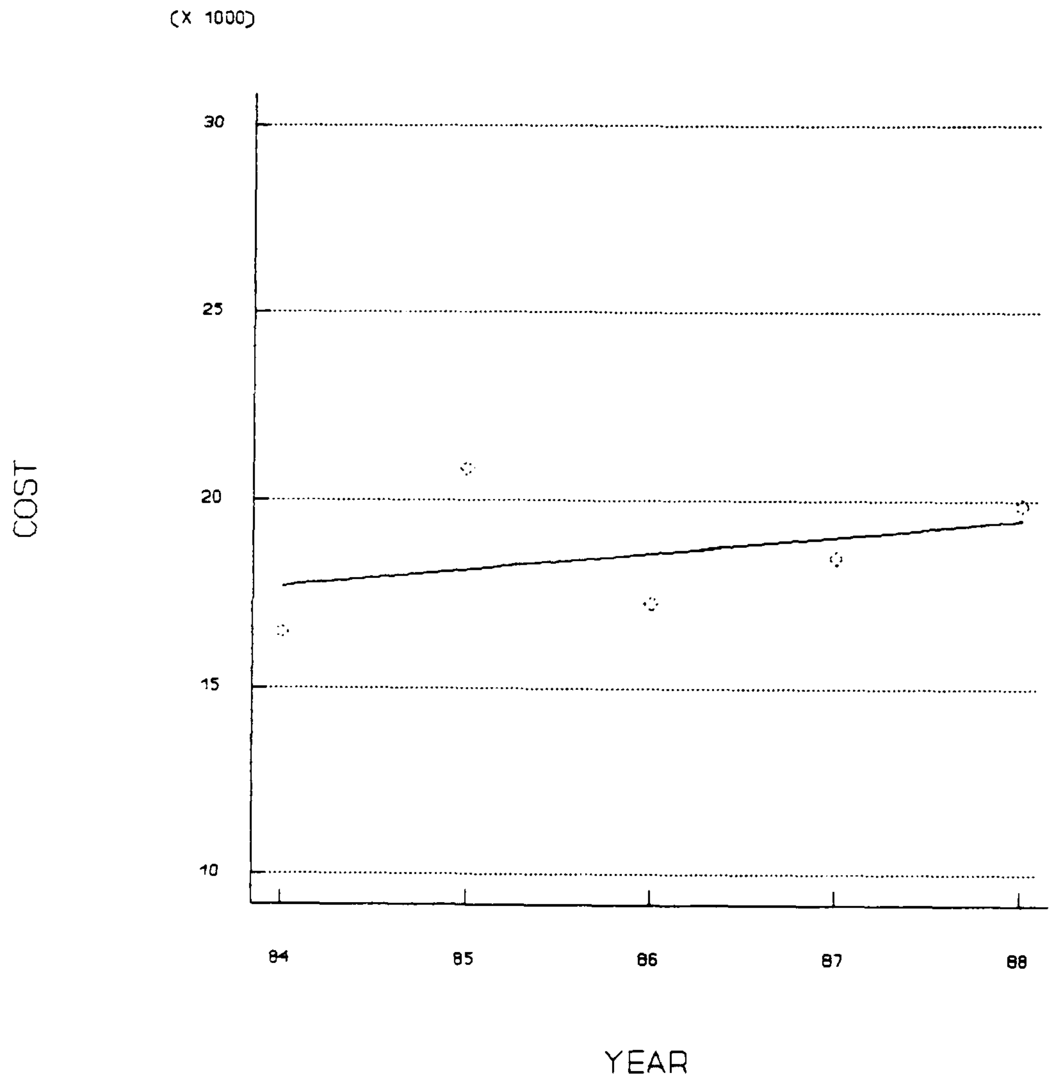

Figure 6: Regression of OCS Cost on Year

TABLE 6. REGRESSION AND ANOVA TABLES FOR USNA COST VS TIME

Regression Analysis - Linear model: Y = a+bX

Dependent variable: USNA.COST Independent variable: USNA.YEAR

Parameter	Estimate	Standard Error	T Value	Prob. Level
Intercept	348586	83077	4.19594	.00406
Slope	-2214.35	988.545	-2.24001	.06008

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Level
Model	2.9420E0008	1	2.9420E0008	5.018E0000	.06008
Error	4.1043E0008	7	5.8633E0007		
Total (Corr.)	7.0463E0008	8			

Correlation Coefficient = -0.64616 R-squared = 41.75 percent
Stnd. Error of Est. = 7657.24

TABLE 7. REGRESSION AND ANOVA TABLES FOR NROTC COST VS TIME

Regression Analysis - Linear model: Y = a+bX

Dependent variable: NROTC.COST Independent variable: NROTC.YEAR

Parameter	Estimate	Standard Error	T Value	Prob. Level
Intercept	21770.6	76842.7	0.283314	.79536
Slope	374.7	893.399	0.419409	.70314

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Level
Model	1404000.9	1	1404000.9	0	.70314
Error	23944878	3	7981626		
Total (Corr.)	25348879	4			

Correlation Coefficient = 0.235345 R-squared = 5.54 percent
Stnd. Error of Est. = 2825.18

TABLE 8. REGRESSION AND ANOVA TABLES FOR OCS COST VS TIME

Regression Analysis - Linear model: Y = a+bX

Dependent variable: OCS.COST   Independent variable: OCS.YEAR

Parameter	Estimate	Standard Error	T Value	Prob. Level
Intercept	-19327.6	52147.1	-0.370636	.73553
Slope	440.9	606.28	0.727222	.51970

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Level
Model	1943928.1	1	1943928.1	1	.51970
Error	11027261	3	3675754		
Total (Corr.)	12971189	4			

Correlation Coefficient = 0.387124   R-squared = 14.99 percent
Stnd. Error of Est. = 1917.23

APPENDIX C: TABLE OF ACCESSIONS

TABLE 9. ACCESSIONS BY SOURCE AND BY YEAR

RUN NAME	SOURCE	YEAR				
		1989	1990	1991	1992	1993
BASE (OC)	USNA	22.46	28.34	35.44	31.09	10.96
	NROTC	28.84	36.50	42.05	44.52	37.17
	NUPOC	14.76	25.02	26.02	19.22	10.22
ONLY 35	USNA	24.17	35.76	46.95	51.63	23.45
	NROTC	28.48	28.09	28.93	27.10	22.88
	NUPOC	14.92	28.97	29.97	26.42	14.54
½ • OC	USNA	22.46	27.81	34.69	29.34	10.91
	NROTC	28.69	36.50	40.93	44.52	36.83
	NUPOC	15.02	27.84	26.62	23.04	10.97
2 • OC	USNA	23.13	28.96	36.63	32.11	11.41
	NROTC	28.06	37.93	42.43	44.50	38.68
	NUPOC	13.42	21.17	24.84	16.34	8.73
POLICY 1	USNA	46.53	54.85	58.85	48.64	25.05
	NROTC	34.57	36.90	42.08	48.32	39.68
	NUPOC	29.52	44.46	40.81	38.77	21.08
POLICY 2	USNA	29.11	42.07	37.95	30.55	15.88
	NROTC	31.21	36.90	38.83	43.07	48.07
	NUPOC	13.88	28.24	31.94	23.07	13.94
POLICY 3	USNA	17.02	14.57	26.45	26.86	14.75
	NROTC	22.75	32.07	36.19	40.59	42.37
	NUPOC	7.35	15.55	23.55	12.87	9.96
POLICY 5	USNA	21.29	25.84	32.90	29.22	12.94
	NROTC	25.77	35.83	39.49	42.00	37.46
	NUPOC	11.81	20.74	23.77	14.78	9.39
RANDOM 1	USNA	19.66	28.93	29.76	25.36	12.68
	NROTC	23.67	34.40	37.75	40.08	35.87
	NUPOC	14.82	22.98	22.00	20.40	23.27
RANDOM 2	USNA	6.12	19.59	42.15	15.27	2.55
	NROTC	32.56	40.25	46.19	52.96	54.60
	NUPOC	9.92	19.11	28.40	27.43	22.84
FIXED	USNA	2.10	59.51	61.16	32.06	0.00
	NROTC	35.65	41.00	47.15	54.22	62.35
	NUPOC	0.00	0.00	0.00	0.00	0.00

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